Food Science for Relief and Development (FSRD)
Case Study | April 2026

Purdue Improved Crop Storage bags: A hermetic storage system to improve food and nutrition security, and income

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(A) **(B)** **(C)**

Figure 1. ***(A)*** *Purdue Improved Crop Storage (PICS^{TM}) 100-kg bag used to store cowpeas.* ***(B)*** *Cowpeas stored in PICS bags.* ***(C)*** *Cowpeas NOT stored in PICS bags.*[1]

PICS bags (Figure 1.A) are a cost-effective storage solution designed to reduce post-harvest losses by protecting a wide range of commodities from pests, moisture, and mold toxins (i.e., aflatoxin). They are made of two high-density polyethylene (HDPE) liners inside a woven polypropylene (PP) bag. The limited oxygen and moisture permeability of those materials and biological respiration originating from the presence of insects creates an airtight environment unfavorable for pests and molds, preserving grain quality. Food science principles play a critical role in the development and effectiveness of PICS bags, helping to maintain nutritional value, sensory properties, and safety of crops, which in turn reduce food waste and improve food and nutrition security in developing regions.

Food Science in Action:

- ✓ Food Packaging
- ✓ Food Safety
- ✓ Food Microbiology
- ✓ Quality Control
- ✓ Food Security
- ✓ Post-harvest Technology

Introduction

In September 2015, all United Nations (UN) members adopted the *2030 Agenda for Sustainable Development* to achieve sustainable economic, social, and environmental development in a balanced and integrated manner, addressing the most pressing global challenges of our time. Among the 17 Sustainable Development Goals (SDGs) in the 2030 Agenda, SDG 2: Zero Hunger aims to “end hunger, achieve food security and improved nutrition, and promote sustainable agriculture” by 2030. However, according to the UN, approximately only 16 percent of the SDGs are progressing to be met globally by 2030, while 84 percent of the

SDGs show limited or no progress, with the SDG 2 on track to be missed by all the 193 UN member states as a result of prevailing undernourishment, obesity, unsustainable agriculture and/or unhealthy diets.[2-4]

Food losses (i.e., the decrease in edible food mass that occurs during agricultural production, post-harvest handling and storage, and processing) are a critical element in the limited progress toward achieving the Zero Hunger goal by 2030. Food losses decrease the quantity and quality of food available for consumption, particularly in developing countries, negatively impacting food security and nutrition. The world's primary annual crop production (i.e., cereals, roots and tubers, sugar crops, vegetables, oil crops, and fruits) is approximately 9.5 billion tons, but it suffers from approximately 13% in food losses.[5,6] At the regional level, it is estimated that post-harvest and storage losses for cereals and legumes in Sub-Saharan Africa are as high as 18%.[7] Hence, the development and implementation of profitable technologies for post-harvest handling and storage to reduce grain losses, adapted to local contexts, locally sourced, and easily accessible, may be valuable to end hunger, achieve food security, and improve nutrition in Sub-Saharan Africa and other developing regions.

Response

Several grain storage techniques (e.g., traditional, chemical, and hermetic systems) have been developed over the years to prevent food losses during production and storage. Hermetic storage has become popular as an alternative to traditional and chemical methods and as an adaptation to conventional storage systems (e.g., underground pits, clay pots, jerrycans, silos, and drums).[7] Commonly used hermetic storage systems include silos, drums, plastic bags, and hermetic containers of different forms and sizes. Among smallholder farmers in sub-Saharan Africa, hermetic bags are the most widely disseminated storage system.[8] Several types of hermetic storage bags are commercially available: Single-layer (e.g., SuperGrainbag™ manufactured by GrainPro Inc.), double-layer (e.g., AgroZ® bags manufactured by A to Z), and triple-layer bags (e.g., PICS bags).[9,10]

While the performance might be impacted over time, PICS bags offer better solutions compared to other technologies, such as single-layer polypropylene bags. Additionally, PICS bags enable farmers to store grains outside of their houses without significantly compromising quality.[11]

In 2007, to improve cowpea storage and address losses due to insect damage and inadequate storage, Purdue University (Indiana, U.S.), under the Purdue Improved Cowpea Storage (PICS) project, launched the use of hermetic storage in triple-layer sacks (i.e., PICS bags). The Bill and Melinda Gates Foundation (BMGF), the United States Agency for International Development (USAID), and others have provided over $25 million to develop and deploy the technology with BMGF acting as primary donor.[9]

Cowpea, an indigenous African legume, constitutes an economical staple food due to its high concentration of essential amino acids such as lysine and tryptophan.[12,13] However, these legumes are susceptible to losses due to insect damage, inadequate storage, and lack of effective post-harvest processing, with conservative estimates of cowpea storage losses of up to 25%.[12]

A 100-kg PICS bag costs about $2 to $3. Though prices appear high, PICS bags are durable, and it has been demonstrated that they may be reusable for several seasons (at least three times).[14]

Initially, PICS bags were designed for Cameroonian farmers to store cowpeas. However, supported by approximately twenty to three thousand village demonstrations in Nigeria, Niger, Burkina Faso, Benin, and Togo, farmers in other countries quickly adopted the technology.[12] Currently, more than 12 million farmers have been trained in the use of PICS technology, and bags are being used in over 40 countries in sub-Saharan Africa, South and East Asia, Latin America, and the Caribbean (Figure 2). Across different regions, over 50 million PICS bags have been sold.[14]

Although PICS bags were initially developed to protect cowpeas against insect attack during storage, it is currently used to store over 20 different commodities and crops, including but not limited to paddy rice, sorghum, cassava, wheat,

Figure 2. *Countries where PICS bags have been used.*[21]

cocoa beans, common beans, coffee, maize, pigeon peas, mung beans, Bambara ground nuts, peanuts, soybeans, and dry fruits (Table 1). With the application of PICS technology to other crops, appropriately, the technology was renamed as the Purdue Improved Crop Storage bags.[12,14-16] Additionally, PICS technology has emerged as an innovative solution for addressing food safety concerns such as pesticide residues and mycotoxin contamination.[12,17-20]

PICS bags are currently manufactured around the world by private companies including 12 companies in Sub-Saharan Africa, 2 companies in Asia, and one company in Central America.[9] PICS bags are produced at a cost between $1 and $1.50 and often sold to farmers for $2 to $3. With sales of over 50 million PICS bags since 2007, it is estimated that farmers have had a return on investment of around $3.0 billion, assuming a cash flow of $25 per 100-kg bag and that each bag is used at least three times.[9,14]

Hermetic storage of grains, also called “sacrificial sealed storage,” is a form of Modified Atmosphere Packaging (MAP). In PICS technology, insects and other aerobic organisms (such as molds) produce through their respiratory metabolism an atmosphere inside hermetic bags, which becomes unfavorable to their survival and reproduction. This process reduces grain damage during storage.[14] PICS technology, also considered a passive hermetic storage solution, is characterized by a significant drop in oxygen levels and an increase in carbon dioxide. It has been observed that when infested cowpeas are stored in PICS bags, oxygen levels drop below 5%, and carbon dioxide levels rise to more than 10%.[22]

Three PICS bags have been designed: 25, 50, and 100 kg. They are made of two high-density polyethylene (HDPE) liners each with a thickness of 80 microns, inside a woven polypropylene (PP) liner (Figure 3). The HDPE inner liners reduce the transfer of oxygen and moisture across the bag, and the tough outer woven liner protects the less tear-resistant HDPE liners.[1,9] The process to fill and close the PICS bags is described and shown in Figure 4.

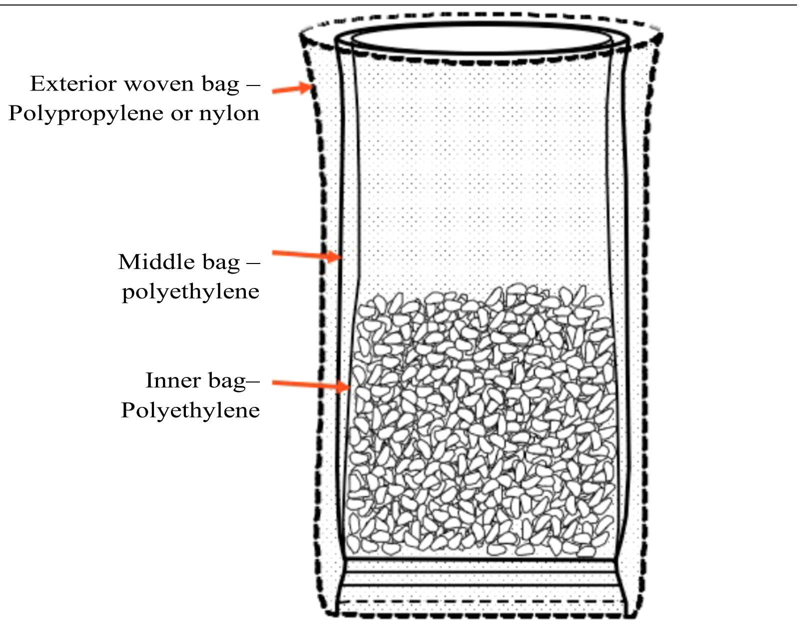

Figure 3. *Food plastic materials used in the triple layer hermetic (i.e., air-tight) PICS bag.*[1,23]

Each component of a PICS bag is designed for multiple functions, contributing to effective hermetic storage. The squat cylindrical shape of the bag reduces the area-to-volume ratio, reducing oxygen and moisture penetration into the bag. The HDPE in the inner liners minimizes the diffusion of oxygen from the exterior environment into the bags. Additionally, the space between the liners reduces the oxygen driving force into the bags.[22,23] Grains and insects play a role as well. The grains interfere with the path of moving oxygen used by insects in the interior of the bags, and they reduce the volume of oxygen inside the bag. Insects deplete oxygen, leading to a negative impact on their survival, and having three layers of bags prevents the insects from re-infesting the grain from the outside. Although insects can make holes in one layer, it is challenging for them to penetrate the 2 HDPE layers.[24]

Additionally, hermetic storage is beneficial in hot and humid tropical climates since it is effective against toxin-producing mold,[9] where, humidity control and airtightness to prevent the reentry of oxygen, insects and moisture are key factors to the success of hermetic storage in minimizing grain losses during storage.[14,25,26]

As compared to other packaging materials with good barrier properties against oxygen, e.g., glass and polyethylene terephthalate (PET), HDPE is a lower oxygen barrier but a good moisture barrier.[28] However, over a short time period, it has been observed in infested grains that the relatively low oxygen transmission rate of a double HDPE layer in PICS bag — each with a thickness of 80 microns, results in hypoxia (i.e., low oxygen levels) which causes insect mortality and stops aflatoxin production.[25] In PICS bags containing cowpea infested with beetle bruchids (*Callosobruchus maculatus*), it has been observed that oxygen levels drop from normal 21% (v/v) into the low 2–5% (v/v) oxygen range within 6 hours.[22] Because, *C. maculatus* and other post-harvest pests that inhabit dry, stored products rely heavily on ambient oxygen to produce metabolic water this induced hypoxia leads to death by desiccation.[22] Grain reinfestation in PICS bags is reduced by the more tear resistant and higher mechanical strength exterior of the woven PP bag which protects the HDPE inner bags during transport and storage.[29]

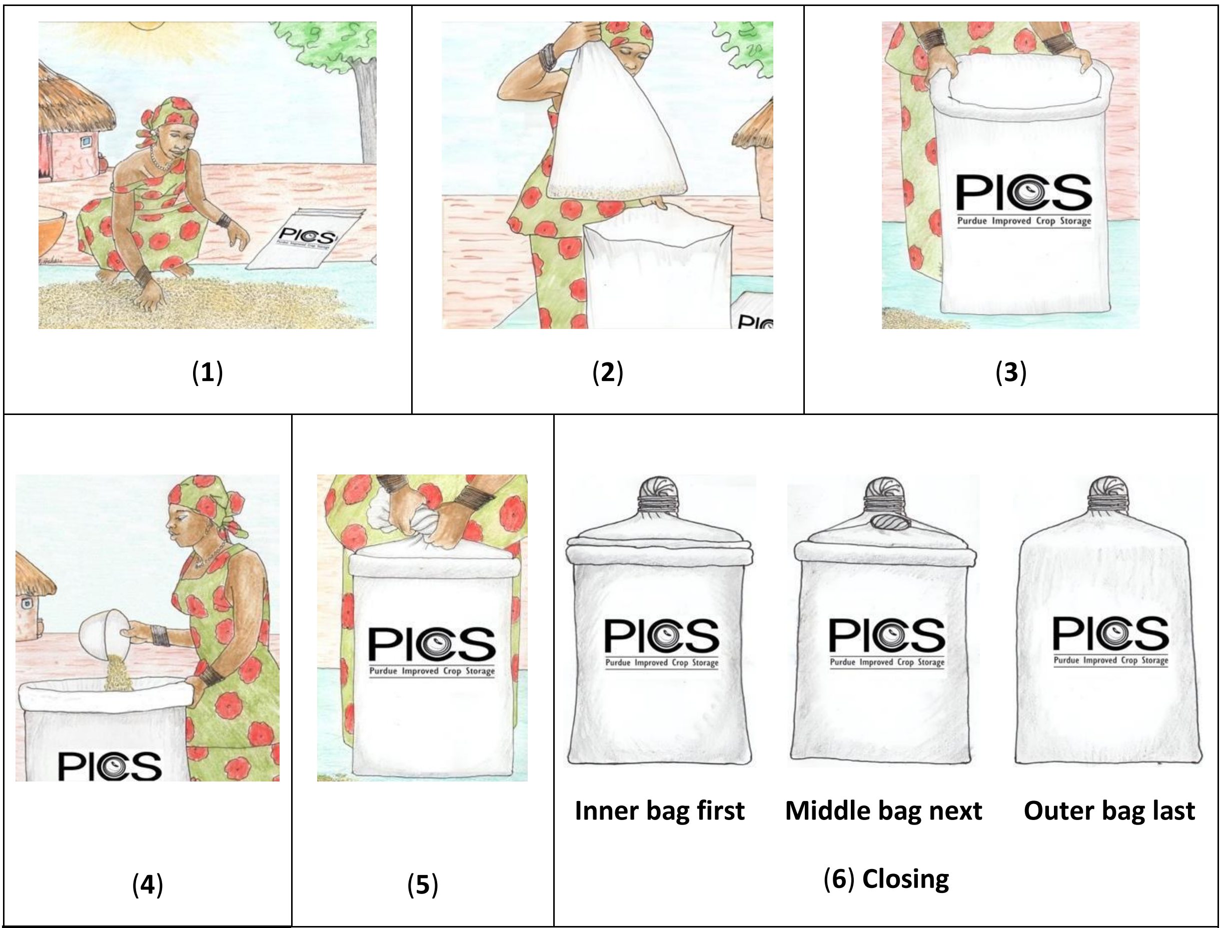

Figure 4. *PICS bag filling and closing process.*[27]

(1) *Procure bags from an approved vendor. Inspect grain to make sure it is dry and clean, and bags have no holes or tears.* ***(2)*** *Add a small amount of grain into the inner liner and fit it inside the second liner.* ***(3)*** *Insert the two liners into the woven bag and fold over the tops of the three bags together.* ***(4)*** *Fill the inner bag leaving a lip for twisting and tying. Pack the grain tightly to remove air.* ***(5)*** *Gently twist the inner bag lip.* ***(6)*** *Fold it over and tie it using a string or cord. Fold and separately tie each of the three bags and place in storage. Storage recommendations:* ***a)*** *Store away from direct sunlight or extreme heat;* ***b)*** *Use elevated platforms to keep bags off the ground;* ***c)*** *Leave space away from walls to facilitate stock inspections;* ***d)*** *Avoid storing in the same area with heavily infested grain.*

Results

Before PICS bags are introduced, farmers often rely on chemicals to control pests during grain storage. However, these chemicals do not always provide complete protection against pests, and they may impose economic strain, pose environmental risks, and threaten the health of farmers and their families.[1,29-31] The transition to PICS bags has significantly benefited farmers, as these bags not only maintain seed quality by preventing moisture absorption from the environment but also protect grains against insects and rodents.[30]

With the adoption of PICS bags, farmers can store their crops long-term, giving them the flexibility to decide when to sell based on market conditions. Before the adoption of PICS bags, farmers had to sell their grains immediately after harvesting due to the challenges of preserving grain quality, primarily due to pest and other post-harvest losses.[32] PICS bags have proven effective in maintaining grain integrity even in harsh environmental conditions (e.g., high humidity).[11]

Testimonial from PICS bags users[33]
"Previously, I would treat my grain with chemicals and pack in gunny bags, but it was not a successful storage method because of insect attacks. PICS bags have changed all that." **Veronica Mwanza, Smallholder Farmer**
"Our grain would get damaged and we would incur losses. But now with these PICS bags, our grain now lasts longer, and our money is safe." **Anna Wambua, Grain Trader**
"The main challenge I have always faced in the business is the menace of weevils attacking and spoiling my peas whenever they are in store. Now with PICS bags, the peas look and smell fresh, as if they have just been brought from the farm. They are very effective; they keep your peas in good shape even after long storage." **Hannah Nsiah, Cowpea Farmer**

Staple grains like cowpeas and maize are essential nutrient sources in developing economies, but post-harvest losses due to insects, compromise food security. Significant consequences due to pest infestation include physical damage to the seed and reduced germination rates. Without appropriate storage conditions, cowpea seeds are susceptible to cowpea beetle bruchids (*Callosobruchus maculatus*) infestation, which can cause seed damage ranging from 80–100% within 5 months of storage (Figures 1.B and 1.C).[1,34] PICS technology is effective, and compared to others, it is a low-cost solution to reduce this damage. However, due to its novelty, there was initial reluctance to quickly adopt it.[12] Nevertheless, once the market for PICS bags was established among cowpea farmers, these novel bags were adopted for other commodities.

Like cowpea, maize is commonly infested by insects such as the grain borer beetle (*Prostephanus truncatus*) and the maize weevil (*Sitophilus zeamais)*. Globally, at least 9% of post-harvest losses are due to insect and mite infestation.[28] Farmers typically control this pest chemically using insecticides like permethrin and deltamethrin. However, another major challenge is the limited access to effective drying methods. Studies estimate that over 65% of maize can be contaminated by fungi prior to harvest, and without proper drying, toxins increase during storage, especially in tropical regions.[17,18,20,30,33] Mycotoxins due to fungi infestation in grain are a critical factor that influences grain quality. Surveys conducted in Togo, Ghana, Burkina Faso, and Benin indicate that maize in those countries is of unacceptable quality, containing insects and exceeding United States Department of Agriculture (USDA) accepted levels of aflatoxin.[35,36] While multiple studies (Table 1) demonstrate that PICS bags can reduce aflatoxin production during storage, initial grain moisture content can impact their effectiveness.[37] Therefore, educating farmers regarding grain moisture content during storage is crucial for maximizing the benefits of PICS technology.

In addition to reduced production of aflatoxins during storage, it has been demonstrated that, when compared to other storage methods, using PICS bags for storage of different grains and legumes (e.g., pigeon peas, mung beans, common beans, and peanuts) provides additional benefits such as better seed germination rates and integrity, higher seed viability and vigor, no visible kernel damage, no weight loss, no kernel discoloration, and reduced rancid flavor[38-43]

The PICS team has generated extensive scientific knowledge, which has contributed to increased support from development partners and governments in investing in food security initiatives and farmer outreach and education. Foundations and government agencies have funded scale-up and commercialization activities. Several factors have contributed to the success of PICS, including farmer participation and training.[44] However, more awareness is needed to increase the adoption of this technology further and thus improve food security in low-income countries.[45]

***Table 1**. Summary of studies conducted by Purdue University on PICS bags–Food Science Related*

Commodity	Area of Study	Country/ Region	Year	Main Findings
Cowpea	Growth of *C. maculatus* in polyethylene bags with different thicknesses (50, 60, 80, 90, 100 µm) and layers (1-2)	Burkina Faso	2011	Bruchid numbers and seed damages were reduced when cowpea was stored in 2 layers of HDPE with a thickness of 80–100 µm. Development of the insect was correlated with oxygen concentrations. Triple bagging was effective in reducing new insects, after 26–28 weeks, no living insects were recorded.[46]
	Mode of action of hermetic storage of cowpea in PICS bags	U.S.	2012	The mode of action is linked to the depletion of oxygen in the container, along with a rise in carbon dioxide, insects cease to feed (in low oxygen). Blocking oxygen supply interferes with the main supply of water for insects.[22]
	Post-harvest storage of cowpea and PICS–performance of varied sizes of bags (50, 100 kg), used and new bags	Niger	2012	Initial levels of oxygen had a concentration of 21% (v/v) but the concentration decreased after grains were infested. After 156 days there were high mortality rates. All bags performed equally well. The inner bag had the most damage due to potential perforations by insects.[34]
	Responses to questions asked by farmers	Niger	2013	HDPE plastic liners improved preservation of the grain. Oxygen and carbon dioxide were homogeneous in all the sections of the bags. Cowpea grains retained high rates of germination for 18 months. The use of insecticides is unnecessary.[47]
	Comparison between PICS and GrainPro SuperGrain™ bags	Niger	2013	Both bags reduced the oxygen level, parameters evaluated (e.g., relative humidity, oxygen concentration, temperature) were similar in both bags. SuperGrain bags showed more holes caused by insects compared to PICS, reusing SuperGrain bags would require an additional woven bag for strength. PICS were more affordable and had higher durability.[48]
	Performance of PICS under extreme environmental conditions–cowpeas against bruchids	Niger	2018	PICS under extreme weather conditions can maintain grain quality, although if stored outside, can reduce grain germination rate & bag but longevity is reduced.[11]
	Comparison of different post-harvest technologies to protect stored cowpea	Niger	2020	PICS bags similarly to other hermetic bags (e.g., EVAL™, AgroZ) create a hypoxic environment that results in the suppression of bruchids; thereby maintaining cowpea quality during storage.[49]
Hibiscus grains	PICS performance against storage insects	Niger	2016	Germination rates in grains were maintained through storage, drops in oxygen and rise of carbon dioxide supported insect mortality.[50]

Paddy rice	Effectiveness of PICS for protecting paddy rice against storage pest and impact on rice germination	Burkina Faso, Ghana, Niger	2016	No perforations in the bag were observed; paddy seeds germination varied depending on the cultivar. Losses due to insects were reduced.[17]
Sorghum	Performance of PICS bags storage on sorghum seeds quality (viability & germination) over 6 months	Purdue University, U.S.	2016	Proper storage of sorghum can preserve its quality for up to 6 months. Seeds must be dry before storing.[51]
	Effectiveness of PICS against insect pest damage over 12 months	Burkina Faso	2019	Decreases in oxygen and increases of carbon dioxide contributed to pest reduction, PICS suppressed the proliferation of initial pests and resulted in the death of secondary pests. Sorghum quality was preserved after 12 months without reducing seed viability.[52]
Cassava chips	Efficacy of using PICS for the storage of cassava chips	Benin	2014	Holes were identified in the inner HDPE layer; hermetic storage was not achieved, potentially due to large air spaces. PICS are not recommended for cassava chips.[31]
Wheat	PICS performance against wheat pest was evaluated	Purdue University, U.S.	2015	PICS bags restricted gas movement across the layers, reducing oxygen for insects while maintaining temperature, humidity and moisture. No aflatoxin was detected.[53]
Dried cocoa beans	Effects of PICS on cocoa beans under small farms conditions	Colombia	2024	PICS storage beans were higher quality at the end of the experiment compared to other bags. However, moisture content, water activity, insect damage, and mold increased with the duration of storage for all bags.[54]
Beans	Comparison between PICS & woven polypropylene bags against *A. obtectus* in beans	Kenya	2015	PICS eradicated pest and bean germination was intact.[40]
Coffee	Impacts of PICS storage, sensory attributes and water activity on coffee beans	Colombia	2022	Triple layer PICS bags are not profitable to coffee growers, instead, the double layer might be a better fit. Using PICS did not affect the coffee price, nor the sensory attributes.[55]
Maize	Destructive effects of *Prostephanus truncatus* and *Sitophilus zeamais* on maize grain and effectiveness of PIC bags	Ghana	2012	Triple bags prevent the development of mycotoxins like aflatoxins and ochratoxins. It also prevents quality loss due to an increase of free fatty acids in the low oxygen environment.[30]

Maize (Cont.)	Comparison of different storage technologies for maize	Purdue University, U.S.	2017	Maize stored under PICS bags kept the initial quality and maintained stable moisture content and germination. Germination rates were lower in infested woven bags in comparison to PICS.[23]
	Aflatoxin mitigation by using PICS for maize storage	Purdue University, U.S.	2014	PICS protected maize against mold growth and aflatoxin production.[20]
	Comparison of performances of PICS, woven polypropylene and jute bags in protecting shelled maize against insect damage	Kenya	2016	PICS were good barriers against moisture fluctuation, storage in PICS resulted in halting destructive losses even for maize that had some level of infestation.[37]
	Assessment of PICS on the production of *Fusarium spp* and levels of aflatoxin production in maize	Kenya	2016	Storage of maize in PICS reduced the population of *Fusarium* spp., therefore, reducing the levels of aflatoxins.[32]
	Effect of PICS bag storage on stored maize quality, based on mold proliferation and aflatoxin contamination	Kenya	2016	Grain integrity was preserved, aflatoxin accumulation was prevented when the moisture content of maize was less than 14%.[37]
	Measurement of aflatoxin in maize after 3 months of storage	Kenya	2016	After 3 months, aflatoxin levels were 71% higher in PP bags compared to PICS bags. PICS bags suppressed the growth of *Aspergillus* spp.[56]
	Evaluation of PICS against insect pest, comparison with woven bags	Purdue University, U.S.	2017	Maize storage in PICS maintained the quality independently from the initial infestation level, and germination rates were maintained. There were no significant differences in insect damage between PICS and woven bags, but germination rates were better in PICS.[23]
	PICS storage for maize seeds during 2 months under high relative humidity conditions	Pakistan	2017	PICS and polypropylene bags were compared. After 2 months, there was no increase in PICS bags' moisture, PP bags' moisture increased by ~3%. Storing in PICS did not affect seeds' germination rates.[57]
	Assessment of PICS utility in retaining carotenoids in biofortified maize		2019	PICS can help in reducing the rate of carotenoid degradation, maintaining nutritional quality. PICS bags reduced the effectiveness in reducing the carotenoid degradation after long-term storage.[18]
	PICS performance when used for storage of maize infested with 2 insects simultaneously	Kenya	2019	Modified air conditions were achieved due to grain respiration and insects, PICS prevented changes in grain moisture, and a decrease of insect population was achieved over the six months of study. The use of chemicals and PICS was ineffective after 16 weeks of storage.[58]

Maize (Cont.)	Comparison of post-harvest methods for storing maize	Benin	2020	No perforations were observed in the second layer of PICS, price variability in different hermetic bags may drive farmer purchasing decision.[34]
	Short-term PICS storage on wet maize and impacts on quality	U.S.	2023	Short term storage can be used to prevent mold and maintain germination rates, minimal fermentation occurs even at high humidity and moisture content.[59]
	The impact of using PICS bags for storing wet maize.	U.S.	2024	Wet maize can be stored in PICS for 21 days; however, the grain developed a fermentation odor and fungal growth was observed.[60]
Pigeon peas Mung beans	Evaluation of the effectiveness (e.g., seed germination, moisture, coat color, aflatoxin contamination, and insect) of using PICS as a storage alternative for pigeon pea	India	2014	PICS prevented insect development and maintained pea integrity. PICS storage grain had higher germination rates in comparison to the traditional used gunny bags. Low levels of aflatoxin were detected. Researchers suggest that PICS allow farmers to store seeds and take the seeds to the market when it's more convenient for them.[43]
	Storage of pigeon pea & mug bean was assessed by measuring insect damage,	Kenya	2014	Grains storage in PICS bags maintained its integrity, by preventing insect damages resulting in seeds with high viability. Moreover, using PICS bags was more efficient than using chemicals for pesticides purposes.[41]
Bambara Groundnuts and peanuts	PICS were used in various levels of *Callosobruchus maculatus,* insect development, and nut damage were assessed	Niger	2014	Insect eggs development was reduced from using PICS, minimal damage in the internal layer suggests that PICS can be reused by groundnut farmers.[38]
	PICS performance for groundnut pod storing	India	2015	PICS bags protected nuts from insects while keeping viability, seed weight, and oil content. Aflatoxin production was retarded.[42]
	PICS performance for the preservation of shelled and unshelled groundnut	Niger	2017	Insect density did not increase after 6.7 months, no weight loss was reported, and the germination rate was maintained. No perforations or damages were reported in the PICS bag liners. Thus, the authors suggest that bags can be reused.[39]
Soybeans	The use of PICS bags for storage of soybeans	U.S.	2022	Seed quality was maintained even at high relative humidity, high germination index, and high vigor of seeds is reported.[61]
Dry fruits	Assess the performance of PICS in preserving dried jujube fruits	Niger	2022	PICS were effective in preserving fruits for 4 months, PICS successfully reduced insect multiplication and damage of dried fruits.[62]

Lessons Learned

- PICS technology has been adopted widely and promises to lead to an increase in the value of grain, overall increased income and food security
- PICS technology provides crop production benefits for farmers as higher germination from some seeds, like cowpea, results in better plant stands and higher yields
- PICS technology eliminates the use of insecticides and is effective in reducing aflatoxin formation, thus positively impacting public health in tropical and subtropical regions
- Although PICS bags cost significantly more than the traditional woven bags, PICS bags are both storage containers and protection methods, eliminating the need for insecticide applications
- Training is critical in increasing awareness and adoption of PICS technology
- Investments by development partners and government agencies are required to increase awareness and adoption of hermetic storage technology
- PICS bags are durable and can be reused for several seasons (at least three times).

Research Areas

- There is a need to explore the development of biodegradable hermetic bags, though increased reuse and cost must be addressed to increase adoption
- Occasional holing of PICS liners requires further investigations to understand under what storage conditions insects damage HDPE liners
- At the time of development, researchers have suggested that resistance development by insects to low oxygen levels could be a potential challenge to PICS technology
- The capability of the bag to preserve the nutritional quality needs to be further investigated.

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